JOURNAL OF
ARBORICULTURE

June 1989
Vol. 15, No. 6

ROOT SYSTEM CONFIGURATION AFFECTS TRANSPLANTING OF HONEYLOCUST AND ENGLISH OAK

by D.K. Struve, T.D. Sydnor[1] and R. Rideout[2]

Abstract. Eight cm (approximately 3 inch) diameter *Gleditsia triacanthos inermis* 'Imperial', Imperial honeylocust, and *Quercus robur,* English oak, were spring dug bare root and root pruned to one of four root configurations, standard, wide-deep, narrow-deep or wide-shallow, to simulate different ball sizes and shapes had the plants been balled and burlaped. The plants were placed in a healing-in area. Survival, leaf and shoot growth were followed for 18 months. All 40 honeylocust trees survived transplanting while three English oaks died. Honeylocust trees given the narrow-deep and wide-shallow root configurations had larger leaves and longer lateral shoots 18 months after transplanting than trees given standard and wide-deep configurations. English oak trees given wide-deep and wide-shallow root configurations had more shoot and leaf growth than did trees given standard or narrow-deep configurations. English oak recovered from transplanting more rapidly than did honeylocust. For both species, shoot and leaf growth during 1986 were not significantly correlated with shoot and leaf growth in 1987.

Root regeneration is essential for the establishment of transplanted trees. Root growth capacity (9) or potential (6) is the measure of the plant's ability to regenerate roots in a given time in a benign environment (9). It varies according to root type, season of the year (a combination of soil and air temperature, soil moisture and planting stock physiology), and species (6). The components of root growth capacity are number and length of roots and their product, total root surface area (9).

Large-diameter, pruned roots have been reported to regenerate more roots than smaller diameter roots (4). However, when root number is expressed as number of roots regenerated per unit root diameter, differences between root sizes are diminished. For instance, 5-15 mm diameter roots regenerated 0.5 roots/mm root diameter, while 15-25 mm diameter roots regenerated 0.7 roots (see 4, Table 1).

The time to complete root regeneration is dependent on whether root regeneration occurs by elongation of existing roots or by initiation of adventitious roots and their subsequent elongation (7). Root regeneration from intact roots is rapid. These intact roots are typically small diameter lateral roots. Plants species in which these roots predominate have fibrous root systems and are considered easy-to-transplant. The elongation rate of these small diameter intact roots is slower than larger diameter roots regenerated from pruned root surfaces (2). There is an inverse relationship between root diameter and time to complete adventitious root regeneration (8, 11). In three-year-old red oak seedlings root regeneration from pruned lateral roots occurred 24 days after transplant, while root regeneration from the main root occurred 49 days after transplant (8). The benefit of high numbers of lateral roots (roots believed to have high regeneration potential) to transplant survival and regrowth under field conditions has been demonstrated with sweetgum (3).

In nursery situations, lateral roots predominate in the upper 23 cm (9 inches) of the soil profile

[1]Associate and Full Professor.
[2]Forestry Technician, Bureau of Forestry, City of Milwaukee, WI.
Salaries and research support provided by State and Federal Funds appropriated to the Ohio Agricultural Research and Development Center, The Ohio State University. Manuscript number 287-88.

(12). At soil depths lower than 9 inches, root density and total root length decrease dramatically. Altering root ball shape could have a dramatic effect on the type, amount and root growth potential of roots contained in the root ball. For instance, a wide-shallow ball would include a greater proportion of small diameter intact lateral roots (roots with high regeneration capacity) than would a narrow-deep ball of similar volume. Increasing ball volume by increasing both the width and depth of a root ball (a wide-deep ball type) might not increase transplant success over a ball of similar width but smaller volume (a wide-shallow ball type) because the lower half of the ball volume would have few, larger diameter roots with low regeneration potental.

By increasing the number of roots with high regeneration potental in a root ball, transplant success should be increased and transplant shock decreased. Transplant shock has been described as an extended period of stress and slow growth due primarily to an imbalance in the shoot/root ratio (13).

Three inch diameter trees of 'Imperial' honeylocust and English oak were dug bare root and root pruned to four "ball" configurations to test the effect of "ball" shape and volume on survival, shoot growth and leaf size after transplanting.

Materials and Methods

On April 23, 1986, 8 cm (3 inch) diameter 'Imperial' honeylocust and English oak were dug from the City of Milwaukee, Wisconsin, Municipal Nursery. The trees had been planted in 1981 as 1.8 m (7 to 8') whips. The whips were planted on 2.1 m between rows and 1.2 m within row spacing (11' by 4'). The English oak were planted in a Mitherton silt loam; honeylocusts were planted in an Aztalan loam. Plants were dug using a 1.5 m (60 inch) U-blade mounted on a front-end loader. Most of the soil was manually removed from the roots using spade forks. The bare root plants were then root pruned to one of four "ball" configurations (see Table 1 for descriptions). The standard configuration approximately 11" root diameter for each inch of trunk diameter, in accordance with AAN standards (1). The narrow-deep configuration was 27" wide. "Ball" depth was chosen so that the volume was equal to the standard configuration. "Ball" volume was calculated by the formula:

$$V = 2/3\ (\pi)R^2D$$

where V = volume, R = radius and D = depth.

The wide-shallow configuration had a diameter/inch trunk diameter ratio of 13" and a volume equal to the standard configuration. A wide-deep configuration was also included. Ten plants were dug for each configuration and species. After root pruning, plants were loaded on a wagon and the roots covered with canvas. No roots were left uncovered for more than 15 minutes.

Plants were taken to a healing-in area and placed on a 1 m within row and 1.5 m between row spacing. A 1:1:1, soil:leaf mold: wood chip, medium was used to cover the roots to a 20 to 30 cm (8-12") depth.

In September 1986 and 1987, 15 to 20 leaves were randomly collected from the crown of each tree. For comparison, similar numbers of leaves were collected from established plants in nursery rows. Total leaf area of each sample was determined with a LI-COR (model LI-3050A) area meter and average leaf area calculated by dividing total area by number of leaves in the sample.

In September 1986, two trees from each species and configuration were dug from the healing-in area and the root systems visually evaluated. The lengths of the five most vigorous shoots in 1985 and 1986 were measured. In September 1987, similar leaf data were collected from the remaining trees and shoot length of the 5 most vigorous shoots in 1985, 1986 and 1987 were measured. All root systems were visually

Table 1. Descriptions of root system configurations used in the study

Configuration	*Width* cm (inches)	*Depth*	*Volume* cm^3 *(inches^3)*
Standard	81 (32)	48 (19)	1.67* (10,187)
Wide-deep	101 (40)	66 (26)	3.57 (21,781)
Narrow-deep	69 (27)	66 (26)	1.67 (10,187)
Wide-shallow	101 (40)	30 (12)	1.67 (10,187)

*Volume calculated by $V = 2/3\ \pi \times R^2 \times D$. where R = radius and D = depth.

evaluated.

Average leaf size and shoot length for each species were analyzed separately using the ONEWAY procedure in SPSS/PC+ (5). Means were separated using L.S.D. The degree of recovery from transplanting was expressed as percent average leaf size of transplanted trees to untransplanted trees and as percent of lateral shoot growth occurring in 1986 or 1987 to that occurring in 1985, the year prior to transplanting. The Correlation procedure in SPSS/PC+ was used to obtain correlation coefficients among average leaf size and shoot growth in 1986 and 1987 for each species.

Results

'Imperial' honeylocust had a more fibrous root system than English oak (Figs 1A and 1B). Root pruning to give the desired configurations removed significant portions of the root systems. For both species, there were a few large diameter roots below 30 cm (12").

Honeylocust: Tree height in spring 1986 averaged 5.4 m (Table 2). There were no differences in lateral shoot growth among the treatments in 1986. Shoot growth in 1986 averaged 4.6 cm (1.8 inches), 20% (4.6/23.5 cm) of the growth in 1985.

In 1987 trees given the narrow-deep and wide-shallow configurations had significantly more shoot growth than trees given the standard or wide-deep configurations. Shoot growth was greater in 1987 than in 1986; the greatest increase was 342%, in the narrow-deep configuration. Shoot growth in 1987 averaged 51% (12/23.5 cm) of the growth in 1985. There was no mortality during the study period.

Average leaf size in 1986 was signficantly greater in trees given the wide-deep configuration than in trees given the standard configuration (Table 3). Leaf size of transplanted trees was

A

B

Figure 1. Root systems of 'Imperial' honeylocust (A) and English oak (B). Photos were taken in April 1986 just prior to root pruning.

Table 2. Lateral shoot elongation of 8 cm (3") diameter 'Imperial' honeylocust and English oak before and after transplanting. Trees were dug bare root in the spring of 1986 and root pruned to one of four root system configurations ("ball" types) before healing-in. Values are means of the 5 longest shoots/tree.

Species & configuration	*Initial tree height m (feet)*	*Shoot elongation in Year cm (inches) 1985*	*1986*	*1987*
Honeylocust				
Standard	5.4A* (17.7)	23.4A (9.4)	4.8A (1.9)	9.1A (3.6)
Wide-deep	5.3A (17.4)	22.6A (8.9)	4.1A (1.6)	10.4A (4.1)
Narrow-deep	5.4A (17.7)	24.1A (9.5)	4.3A (1.7)	14.7B (5.8)
Wide-shallow	5.4A (17.7)	23.8A (9.4)	4.6A (1.8)	14.5B (5.7)
English oak				
Standard	6.0A (19.7)	19.9A (7.8)	9.1A (3.5)	4.6A (1.8)
Wide-deep	6.0A (19.7)	19.8A (7.8)	13.5B (5.3)	19.6B (7.7)
Narrow-deep	5.7A (18.7)	18.7A (7.4)	12.2B (4.8)	3.6A (1.4)
Wide-shallow	6.8A (22.3)	22.6B (8.9)	12.7B (5.0)	18.8B (7.4)

*Means within a column and species followed by different letters are significantly different from each other using L.S.D., 0.05 level.

signficantly less (32%) than untransplanted trees (16.7/52.4 cm^2). In 1987 average leaf size was significantly greater in plants given the narrow-deep than in trees given the standard and wide-deep configurations. Average leaf size of transplanted trees in 1987 was 24% of untransplanted trees (17.1/70.8 cm^2). The decrease in average leaf size of transplanted trees relative to untransplanted trees between 1986 and 1987 can be attributed to an increase in leaf size of untransplanted trees, not to a decrease in transplanted tree leaf size. Average leaf size of transplanted trees was 16.9 and 17.1 cm^2 for 1986 and 1987, respectively.

Significant root regeneration occurred by September 1986 (Fig 2). Many 2-3 mm diameter roots were regenerated from intact root tips and near the pruned surface of larger diameter roots (roots ► 0.5 cm). By September 1987, it was common to find regenerated roots greater than 1 m in length, regardless of the root configuration.

English oak: Tree height in spring 1986 averaged 6.2 m, ranging from 5.7 to 6.8 (Table 2). The differences in initial tree height were not significant ($p = 0.18$). Shoot growth in 1986 was significantly less for trees given the standard root configuration than for the other configurations. Shoot growth in 1986 averaged over all root configurations was 54% of the growth in 1985 (10.9/20.4 cm).

Trees given the wide-deep and wide-shallow configurations had significantly greater shoot growth in 1987 than trees given the standard and narrow-deep configurations. Shoot growth in 1987 of trees given the wide-deep configuration 99% of the shoot growth in 1985. Shoot growth for trees given the wide-shallow root configuration was 83% of the growth in 1985. Averaged over

Figure 2. Root regeneration typical of 'Imperial' honeylocust by September 1986. Trees were transplanted in April 1986. This type of root regeneration was typical in all trees, regardless of "ball" type.

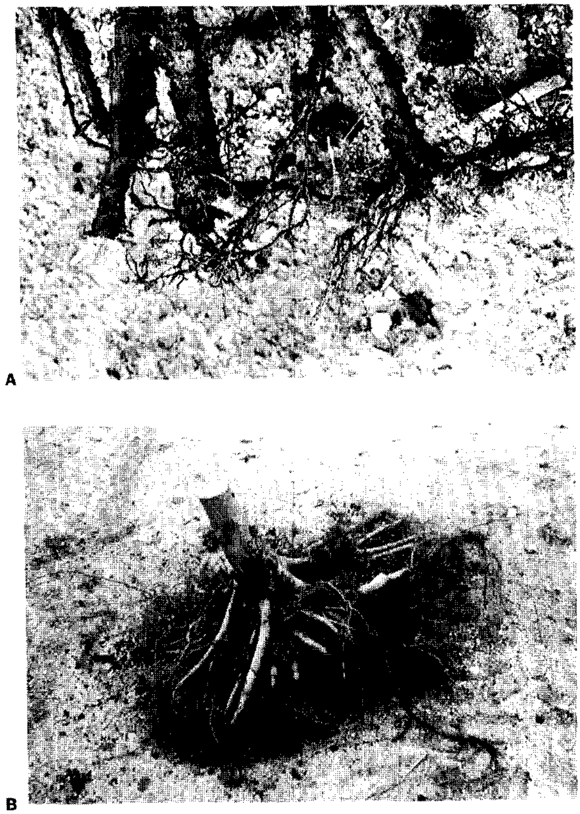

Figure 3. Root regeneration typical of English oak in September 1986 (A) and September 1987 (B). Trees were transplanted in April 1986.

all configurations, shoot growth in 1987 was 61% of the growth in 1985.

In 1986 there were no differences in average leaf size among configuration treatments (Table 3). Average leaf size of transplanted trees was 39% of untransplanted trees (13.6/35.3 cm^2). In 1987 trees given the wide-deep configuration had significantly larger leaves than trees given the wide-shallow configuration. Average leaf size of the trees given the narrow-deep configuration was 92% of leaves of untransplanted trees. Leaf size of transplanted trees averaged over all configurations, was 80% of untransplanted trees (22.6/28.4 cm^2). The increase in transplanted leaf size was due to an increase in 1987 leaf size and to smaller leaves of untransplanted trees in 1987.

Few roots had been regenerated by fall 1986 (Fig. 3A). Most root regeneration occurred from pruned root surfaces. Typically new root length was less than 20 cm. By September 1987, significant root regeneration had occurred (contrast Figs. 3A and 3B). Most regeneration was from small diameter lateral roots. Some roots exceeded 0.6 m (2 feet) in length.

Survival through 1986 was 100%. By 1987, two trees given the standard and one tree given the narrow-deep configuration treatments died.

For both species, correlations among average leaf size and shoot growth in 1986 and 1987 were low (maximum R = 0.39 for average leaf size and lateral shoot growth in 1987) and none was significant at the 0.05 level (data not presented).

Discussion

In this study, "ball" diameter was decreased by 15% (narrow-deep) or increased by 25% (wide-shallow and wide-deep) over the standard "ball" type. Root lengths contained in these "ball" configurations for these species is not known. However, with blue spruce, total root length has been estimated at two soil depths for a 5' radius from the trunk (12). Using their Figure 2, the percent change in total root length contained in a root ball 25% greater or 15% less than the standard size (115 cm diameter and 46 cm deep) can be estimated. An 86 cm diameter ball (15% less) would contain 63% of the total root length of the standard ball. A 136 cm ball (25% greater) would contain 128% more total root length. Using these estimates, the "ball" configurations used in this study would have altered total root length by 204% (wide-deep verses narrow-shallow). If the spruce data are used as an approximation of honeylocust, it is surprising that decreasing "ball" volume this dramatically would increase growth following transplanting; 1987 shoot growth of the narrow-deep "ball" was the same as the wide-shallow.

Altering English oak "ball" configuration had a significant effect on growth following transplanting; contrast 1987 shoot growth of the wide-deep and wide-shallow with the standard and narrow-deep types. "Ball" shape was more important to regrowth than was "ball" volume. Although the wide-shallow configuration had over 200% less volume than the wide-deep configuration

Table 3. Average leaf size of transplanted and untransplanted 8 cm (3") diameter 'Imperial' honeylocust and English oak. Trees were dug bare root in April 1986 and root pruned to one of four root system configurations ("ball" types) before healing-in. Leaves were collected in September of each year. Each value is the grand mean of 15 to 20 leaves/tree and 10 trees/ball type.

Species &	*Average leaf size, cm^2 (or in^2)*	
configuration	*1986*	*1987*
Honeylocust		
Standard	14.2A* (2.2)	15.6A (2.4)
Wide-deep	20.5B (3.2)	16.1A (2.5)
Narrow-deep	15.2A (2.4)	19.5B (3.0)
Wide-shallow	17.7AB (2.7)	17.2AB (2.7)
Untransplanted	52.4C (8.1)	70.8C (11.0)
English oak		
Standard	14.2A (2.2)	21.1AB (3.3)
Wide-deep	14.0A (2.2)	26.2BC (4.1)
Narrow-deep	12.6A (2.0)	19.3A (3.0)
Wide-shallow	13.6A (2.1)	23.8AB (3.7)
Untransplanted	35.3C (5.5)	28.4C (4.4)

*Means within a column and species followed by different letters are significantly different from each other using L.S.D., 0.05 level.

there was no difference in shoot growth or leaf size between the "ball" configurations in 1987. This agrees with the observation that the lower portions of the root system had a few larger diameter roots and the hypothesis that these roots have low root regeneration capacity, relative to roots in the upper portions of the ball.

Based on lateral shoot growth and average leaf size, English oak recovered more rapidly from transplanting than did 'Imperial' honeylocust. By 1987 English oak lateral shoot growth was 61% of that in 1985, whereas honeylocust shoot growth averaged 51%. English oak leaves averaged 80% and honeylocust leaves 24% of untransplanted trees in 1987. This is in contrast to English oak's reputation of being more difficult to transplant than honeylocust. In this study, differences in root morphology did affect transplant survival. However, the degree to which differences in root system morphology affects recovery from transplanting must be questioned.

The differences in shoot growth (recovery) between the species might be attributed to differences in assimilate partitioning (where the photosynthate was preferentially sent); honeylocust appeared to have regenerated a more extensive root system than English oak (contrast figs. 2 with 3a and 3b). The conditions in this study (especially the high organic mulch used in healing-in) were more favorable to root growth than conditions at most planting sites. The high survival rates and rate of regrowth can also be attributed, in part, to the favorable planting conditions and short time period between digging and healing-in.

Leaf size and shoot growth during 1986 were not significantly correlated with leaf size or lateral shoot growth during 1987. In this study, these measures of plant growth can not be used as indicators of recovery from transplanting. Additional information, such as total leaf surface area per tree, net photosynthesis per unit leaf area and length of leaf display, probably are needed.

Acknowledgment. This research was supported in part by a grant from the International Society of Arboriculture and the City of Milwaukee, Department of Public Works, Bureau of Forestry.

Literature Cited

1. Annon. 1986. American Standards for Nursery Stock. American Association of Nurserymen, Washington, D.C. 32pp.
2. Arnold, M.A. 1987. Cupric carbonate modification of *Quercus rubra* and *Fraxinus pennsylvanica* root systems and implications for production and transplant. M.S. Thesis. The Ohio State University.
3. Kormanik, P.P. *Lateral root morphology as an expression of sweetgum seedling quality.* Forest Sci. 32: 595-604.
4. Lumis, G.P. 1982. *Stimulating root regeneration of landscape-size red oak with auxin root sprays.* J. Arboric. 8:325-326.
5. Norusis, M.J. 1987. SPSS/PC+^{tm}:SPSS/PC+ for the IBM PC/XT/AT. SPSS Inc. Chicago, IL.
6. Richie, G.A. and J.R. Dunlap. 1980. *Root growth potential: its development and expression in forest tree seedlings.* N.Z.J. For. Res. 10:218-248.
7. Stone, E.C. and G.H. Schubert. 1959. *Root regeneration by ponderosa pine seedlings at different times of the year.* For. Sci. 5:322-332.
8. Struve, D.K. and W.T. Rhodus. 1988. *Phenyl indole-3-thiolobutyrate increases growth of transplanted 1-0 red oak.* Can. J. For. Res. 18: 131-134.
9. Sutton, R.F. 1980. *Planting stock quality, root growth capacity and field performance of three boreal conifers.* N.Z. J. For. Res. 10:54-71.
10. Sutton, R.F. 1987. *Root growth capacity and field performance of jack pine and black spruce in boreal stand establishment in Ontario.* Can. J. For. Res. 17: 794-804.
11. Watson, G.W. and E.B. Himelick. 1982. *Seasonal variation in root regeneration of transplanted trees.* J. Arboric. 8: 305-310.
12. Watson, G.W. and T.D. Sydnor. 1987. *The effect of root pruning on the root system of nursery trees.* J. Arboric. 13:126-130.
13. Watson, G.W. 1986. *Cultural practices can influence root development for better transplanting success.* J. Environ. Hort. 4:32-34.

Department of Horticulture
The Ohio State University
Columbus, Ohio 43210